AD

TECHNICAL REPORT

70-13-CE

A STUDY OF FELTS FOR PERSONAL ARMOR

by

W. James Lyons, Frank L. Scardino

and

B. C. Goswami

Textile Research Institute

Princeton, New Jersey

Contract No. DAAG 17-68-C-0040

August 1969

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing & Personal Life Support Equipment Laboratory

TS-164

This document has been approved for
public release and sale; its distribution
is unlimited

AD________

TECHNICAL REPORT

70-13-CE

A STUDY OF FELTS FOR PERSONAL ARMOR

by

W. James Lyons
Frank L. Scardino
B. C. Goswami

Textile Research Institute
Princeton, N. J.

Contract No. DAA17-68-C-0040

Project Reference:
IM624101D504

Series: TS-164

August 1969

Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

An interest in needled punched felt has been strongly evident since 1963, when initial assessment of this material by the U. S. Army Natick Laboratories indicated that at the lower areal densities (6 to 8 oz./ft^2) needled punched nylon felt exhibited the highest ballistic limits of any known material against the fragment simulators used under current evaluation criteria. Subsequent development of needled punched nylon felt resulted in the establishment of two specifications for personal armor applications.

Studies were then initiated by the U. S. Army Natick Laboratories to gain an understanding of the mechanisms involved in felt penetration as a basis for further development of this material to obtain greater effectiveness. One study indicated that cohesive forces developed in felt were major factors limiting fragment penetration. High cohesive forces occurring without significant fiber breakage upon felt rupture were associated with the high ballistic limits observed.

This report pertains to the influence of various geometric and mechanical characteristics of fibers on the cohesion of felts and also the effect of blends and manufacturing variables on felt cohesion.

Upon completion of the ballistic tests now being conducted by the U. S. Army Natick Laboratories on the material investigated by the Textile Research Institute, a study will be made to determine the relationship between ballistic performance and the fiber and felt characteristics discussed in this report.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This study was concerned with the influence of various geometric and mechanical characteristics of the constituent fibers, and some processing factors such as the amount of needling and the blending of fibers, on the cohesion of needled felts. Tests were conducted on single fibers for surface-roughness and frictional-force characteristics (the latter only in Phase I of the program), and mechanical properties. Length analyses were also made on groups of fiber samples.

The observed surface-roughness parameters did not differ sufficiently among the various samples to permit any conclusions regarding the influence of this property on the cohesion of felts. The frictional-force measurements failed to provide any data that could be significantly correlated with the cohesion behavior of felts.

From the length analyses of the fibers taken from the felts before and after deformation, there was apparently no fiber breakage during the rupture of felts. This observation, and the results obtained on the mechanical properties of single fibers and cohesion of felts, led to the conclusion that fiber tenacity does not play an important role in determining the cohesion of needled felts.

The felts made from fibers having no crimp had greater cohesion. Increased needling brought about a slight, though not significant, increase in cohesion. In general, the results of the study showed that processing variables such as amount of needling, the blending of fibers differing in single-fiber properties (blending of polypropylene and nylon 66, in the present study), and interactions at the processing stage seem to be the predominant factors influencing the cohesion properties of felts.

In an extension of this study, ballistic tests will be made on the seven felt samples studied in Phase II to determine whether a correlation can be drawn between the results of such ballistic tests and the cohesion properties of felts.

1. Introduction

The general objectives of this study were:

a. To determine the influence of various geometric and mechanical characteristics of the component fibers on the cohesion (force-extension behavior) of felts.

b. To evaluate the effect of the amount of needle punching on the cohesion of felts.

c. To assess the role of fiber breakage in the tensile deformation of felts.

For the implementation of these objectives, this investigation resulted in two phases, dictated by the availability of felt samples. In the first preliminary phase, tests were conducted on samples of felt produced on pilot-plant equipment at the U. S. Army Natick Laboratories. In the second phase, a set of seven felt samples manufactured by The Felters Company under Government contract[1], were studied.

2. Phase I - Preliminary Study

a. Samples

The materials furnished by the U. S. Army Natick Laboratories for study in this Phase of the program included:

(1) Two samples of 3-inch, 6-denier high-tenacity (tire-cord type) nylon 66 fiber (raw stock), one with regular crimp and one without crimp (samples SFA-2-1 and -3-1, respectively).

(2) Portions of batts, weighing 4 oz/sq yd, prepared from each of the above samples (SFA-2-2 and -3-2, respectively).

(3) Portions of needled felts prepared from each type of batt. These felts were produced by first doubling the 4-oz/sq yd batts (yielding 8 oz/sq yd), and

giving the assemblies 277 penetrations per square inch (ppsi). The resultant assemblies were then doubled and given another 277 ppsi, producing final felt samples weighing about 16 oz/sq yd (SFA-2-3 and -3-3, respectively).

(4) Same as in (3) above, but given 454 ppsi (SFA-4-3 and -5-3, respectively).

(5) Same as in (3) above, but given 554 ppsi (SFA-6-3 and -7-3, respectively).

For convenient reference, these samples are listed in Table I. The coding in the fifth column, such as "277 x 2", indicates that a certain penetration density was given the batts and subsequently was given to the assembly of batts.

TABLE I

PARTICULARS OF SAMPLE MATERIALS

Sample Identi-fication	Fiber Crimp	Stage of Processing	Nominal Areal Density (oz/sq yd)	Needle Punching (ppsi)
SFA-2-1	100%	raw stock	not applicable	-
2-2	"	batt	4	-
2-3	"	needled felt	16	277 x 2
SFA-3-1	none	raw stock	not applicable	-
3-2	"	batt	4	-
3-3	"	needled felt	16	277 x 2
SFA-4-3	100%	" "	16	454 x 2
SFA-5-3	none	" "	16	454 x 2
SFA-6-3	100%	" "	16	554 x 2
SFA-7-3	none	" "	16	554 x 2

b. Experimental

(1) Fiber Studies

Surface Roughness

Individual fibers were carefully extracted from the batts (SFA-2-2 and -3-2) and two of the felts (SFA -2-3 and -3-3), and mounted on yokes under minimal tension. After the samples had been conditioned, surface-roughness measurements were made on 10 specimens of each sample, according to the usual method[2] employed in the laboratories of the Textile Research Institute (TRI).

The results are given in Table II. They tend to show, on the basis of the values of average asperity count, that there are effects of crimping and needle-punching on the roughness of fibers. The differences in the values are believed, however, to have no practical significance. The values themselves are of the same order of magnitude, and on the basis of experience with roughness measurements at TRI[3], would be judged to represent very smooth fiber surfaces. This observation agrees with the fact that the nylon fibers employed in these batts and felts are of the tire-cord type. Normally, fibers of this type are produced with little or no delusterant (such as TiO_2), the addition of which can substantially alter the surface roughness of the fibers[3].

TABLE II

SURFACE-ROUGHNESS CHARACTERISTICS OF FIBERS

Fiber Sample	Source	Average Asperity Count	Average Height (arbitrary units)
Crimped	batt	14	2.6
"	felt	13	1.6
Non-crimped	batt	42	2.4
"	felt	26	2.4

Frictional Force

Single-fiber specimens were carefully removed from the two samples of raw stock (SFA-2-1 and -3-1), and mounted on yokes under minimal tension. After the specimens had been conditioned, frictional force measurements were made on the TRI analyzer[4]. The usual section of a stainless-steel razor blade was used as the sliding element. Ten specimens each of the crimped and uncrimped fiber samples were tested with a standard normal load of 15.3 mg. Static and kinetic frictional forces were determined from stick-slip curves obtained during testing. The average values are presented in Table III.

TABLE III

FRICTIONAL CHARACTERISTICS OF FIBERS BEFORE PROCESSING

Fiber Sample	Frictional Force (mg) static	kinetic
Crimped	17.5	15.6
Non-crimped	12.8	11.9

Statistical analysis, employing the "Student" t-test, indicates that the frictional values for the crimped sample are significantly greater (at the 99% level of probability) than for the uncrimped sample. It is difficult to interpret this difference since it is not known what effect the crimping operation, and a heat-setting stage that probably accompanies it, has in modifying the nature of the fiber surface. Presumably, a processing finish is applied to the nylon tow, but at what stage is presently unknown. Conceivably, the lubricating properties of such a finish originally applied to tow, before crimping, could be importantly altered by the heat-setting treatment, in such a way as to account for the observed differences in frictional behavior.

Mechanical Properties

Tensile tests were conducted on single fibers removed from raw stock (SFA-2-1 and -3-1) and two of the felts (SFA-2-3 and -3-3). Individual fibers were mounted on metallic tabs at a gauge length of one inch. Each sample was tested on a tensile instrument at the above gauge length, with an extension rate of 50% per minute, after linear densities had been determined by the vibroscope method. The average results of the measurements are given in Table IV.

TABLE IV

MECHANICAL PROPERTIES OF SINGLE FIBERS

Fiber Sample	Source	Linear Density (den)	Textile Modulus (g/den)	Breaking Tenacity (g/den)	Breaking Extension (%)
Crimped	raw stock	6.4	59.4	8.4	17.5
"	felt	7.1	50.1	6.9	16.5
Non-Crimped	raw stock	6.6	58.4	6.3	11.8
" "	felt	6.2	80.3	9.2	17.5

The results indicate that the crimped fibers from raw stock have a significantly higher breaking tenacity than the corresponding non-crimped sample; the trend is the opposite in the case of fibers from the felts. The non-crimped fibers from felts also show a comparatively higher modulus value than the corresponding crimped sample. This could perhaps be due to the deformation and stress concentration brought about by the crimping process as well as unequal damage sustained in the needling process.

The higher breaking extension of the crimped fibers from raw stock, compared to the non-crimped, reflects the fact that, as measured in these tests, this parameter includes uncrimping extension. However, the breaking extension of the original non-crimped fibers from the felt is about the same as that of the crimped fibers, suggesting that needling is an effective crimping process, when applied to non-crimped material. But needling evidently does not

enhance the crimp of fibers already crimped as raw stock; the small difference between the breaking extensions of the two crimped samples is not statistically significant.

Length Analysis

To determine whether the deformation of felts is accompanied by fiber breakage, fibers were removed from two felt specimens (SFA-2-3 and -3-3) ruptured in cohesion (tensile) tests. The fibers were taken at random from the areas of stress concentration and of rupture (Figure 1), and along with fibers from felts before testing were analyzed for length according to the WIRA method[5]. From the results given in Table V the average length of fibers from the ruptured felts does not differ significantly from the average for fibers from felts before deformation. These results indicate that under the conditions used in the present study, for the tensile deformation of the felts, little if any fiber breakage occurs. From this observation it could also be inferred that the single-fiber tenacity does not have an important part in deciding the level of maximum force, adopted as a measure of cohesion.

TABLE V

AVERAGE LENGTH OF FIBERS

Fiber Sample	From Felts Before Tensile Testing (in.)	From Rupture Area of Felt Strips (in.)	From Area of Stress Concentration (in.)
Crimped	2.81	2.81	2.82
Non-Crimped	2.52	2.86	2.94

(2) Cohesion Properties of Felts

To conduct cohesion tests of felts, specimens of 2 inch x 8 inch dimensions* were cut from each of the six

* These dimensions were chosen in substantial conformance with the recommended standard of ASTM for the testing of felts[6].

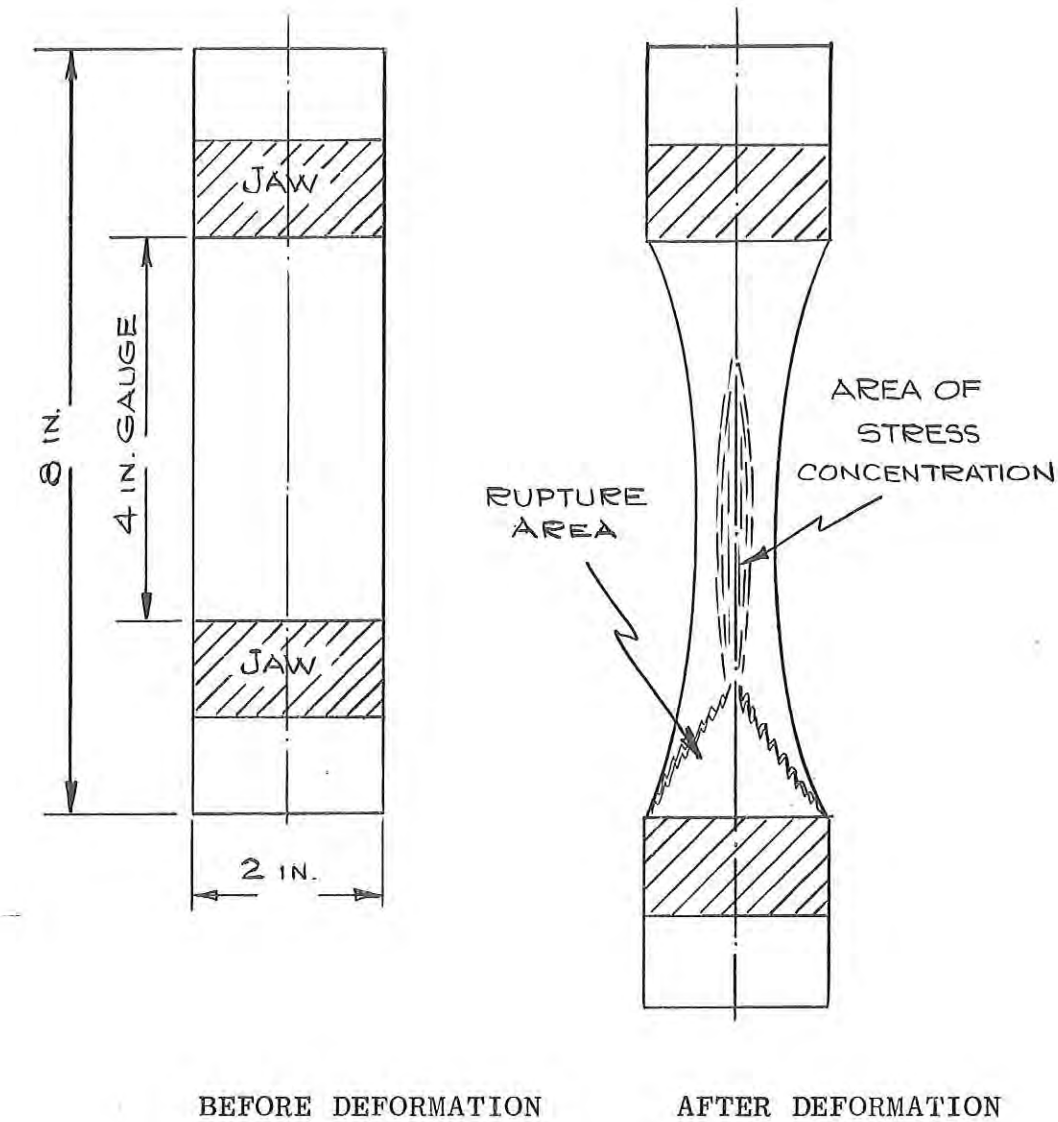
needled felts listed in Table I. The lengthwise axes of the specimens were in both the processing (or machine) and transverse directions. After conditioning, the specimens were extended to rupture on a tensile tester at a gauge length of 4 inches with a rate of extension of 50% per minute. In the interpretation of the results of these cohesion tests (Table VI) it must be noted that, for purposes of comparison, the recorded forces should be corrected (normalized) for areal density or thickness.

From these results it appears that, in all cases, fibers having no crimp seem to produce the greater cohesion, in both the machine and transverse directions. Also increased needling is shown to bring about increased cohesion of crimped and non-crimped samples, but at different rates. All of these conclusions are valid, whether based on the observed maximum forces or on normalized values. Cohesion is much greater in the machine direction than in the transverse direction, as would be expected as a reflection of the orientation given the fibers in the batts by the carding process. The felts composed of crimped fibers show higher extensions to maximum force than do the non-crimped counterparts. There is no significant change in the extension to maximum force with a change in the amount of needling, in either the crimped or non-crimped samples.

c. Discussion of Results

Since surface-roughness measurements made on fibers from batts and felts in this Phase (Table II) indicate that there are no significant differences between the samples (all being relatively smooth), no conclusions as to the relevancy of this fiber parameter to the cohesion of felts can be drawn.

The present results on single-fiber frictional behavior (Table III) bear no reconcilable relationship to the cohesion of felts prepared from the fiber samples on which the friction tests were made. The unavoidable conclusion from these experiments is that single-fiber friction tests provide no data that can be related by a simple, known formula to the behavior of fiber assemblies, with regard to their cohesion. Evidently, the response of fiber assemblies, such as felts, to the application of mechanical loads is controlled by fiber-to-fiber interactions, involving, among other factors, fiber entanglement, and in which, generally, fiber surface friction seems to be relegated to a minor role.



BEFORE DEFORMATION AFTER DEFORMATION

FIGURE 1. SPECIMEN FOR COHESION TEST

TABLE VI

COHESION PROPERTIES OF NYLON FELTS

Fiber Sample	Needle Punching (ppsi)	Measured Areal Den. (oz/sq yd)	Maximum Force (lb)	Exten. to Max. Force (%)	Force at 25% Exten. (lb)	Force at 50% Exten. (lb)
		MACHINE DIRECTION				
Crimped	277x2	16.0	175	134	2	8
Non-crimped	"	13.5	530	57	62	430
Crimped	454x2	15.6	285	128	6	20
Non-crimped	"	17.1	582	55	66	475
Crimped	554x2	18.4	417	127	8	32
Non-crimped	"	16.7	684	68	36	370
		TRANSVERSE DIRECTION				
Crimped	277x2	16.1	38	202	0.4	1.2
Non-crimped	"	-	not available		-	-
Crimped	454x2	15.2	56	220	1.2	2.4
Non-crimped	"	17.5	176	120	2.5	6.0
Crimped	554x2	16.6	118	185	1.5	4.0
Non-crimped	"	16.2	276	104	6.5	24.0

The mechanical properties, especially breaking tenacity, of the component fibers (Table IV) appear to have little or no influence on the cohesion of felts. Evidently the presence or absence of fiber crimp strongly masks whatever influences single-fiber properties might have.

3. Phase II - Study of Commercially Produced Felts

a. Samples

The seven felt samples used in this study were made commercially from nylon 66, (from two different producers), nylon 66, polypropylene, and blends of nylon 66 and polypropylene staple fibers. The particulars of the needle-punched felts are listed in Table VII. The fibers of

TABLE VII

PARTICULARS OF SAMPLE FELTS

Sample Identification	Style[1] Number	Fiber Type[2]	Fiber Producer	Nominal Areal Den. (oz/sq yd)
SFA-9	2	nylon 66	A	19.0
SFA-10	3	nylon 66	B	16.8
SFA-11	4[3]	nylon 66	B	19.4
SFA-12	9	nylon 66	A	21.0
SFA-13	5	nylon 6	C	15.7
SFA-14	7	polypropylene	D	16.0
SFA-15	8	{polypropylene & nylon 66}[4]	B	19.3

[1] Style Nos. 2,3,4,5,7 and 8 had 277 ppsi; Style No. 9 454 ppsi.
[2] All fibers were nominally of 6 dpf. and 3.5-4.0-in. length, before crimping.
[3] Contained crimp-set fiber.
[4] 50% polypropylene/50% nylon, by weight.

all polymer types were identified as of bright, high-tenacity quality. The method of preparation of the felts, as described by the manufacturer[1], is summarized as follows:

Batts weighing 5 to 6 oz/sq yd were first formed by

laying a "card web at the minimum possible angle on the needle-loom feed apron." For six of the styles, each batt was then needled with 227 ppsi. The finished felt was finally formed by combining three such punched batts, and giving the assembly another 227 ppsi (Style Nos. 2,3,4,5,7 and 8). A similar procedure was followed for the seventh style (No. 9), except that the batts and felt were given 454 ppsi, instead of 277 ppsi. All felts were pressed at temperatures from 280° to 300°F, except those containing polypropylene, for which the temperature ranged between 210° and 230°F.

b. Experimental

(1) Fiber Studies

A sufficient number of fiber specimens were carefully extracted, at random, from the body of each felt specimen, for the single-fiber and length-analysis tests.

Surface Roughness

Surface-roughness measurements were made on fiber specimens from each of the felt samples. Single fibers were mounted on yokes under minimal tension, conditioned, and then tested on the TRI analyzer in the usual manner[3]. The average values obtained for the two parameters are given in Table VIII. While the results on the asperity counts would appear to indicate that some fiber samples have rougher surfaces than others, the same conclusion must be drawn here as was reached previously, namely, that differences here have no practical significance. The values in Table VIII are of the same order of magnitude among themselves, and their range (13 to 47) is about the same as that recorded in Table II for the earlier nylon 66 samples (13 to 42). As was the further conclusion mentioned previously, the values are representative of very smooth fiber surfaces, as would be expected for commercial, bright filaments spun for mechanical applications.

TABLE VIII

SURFACE ROUGHNESS CHARACTERISTICS OF FIBERS

Style Number	Fiber Type	Fiber Producer	Average Asperity Count	Average Asperity Height (arbitrary units)
2	nylon 66	A	39	4.6
3	nylon 66	B	13	4.0
4	nylon 66	B	21	3.9
9	nylon 66	A	47	6.8
5	nylon 6	C	20	7.9
7	polypropylene	D	47	4.8
8	polypropylene & nylon 66	D B	37*	5.7*

* Average values for specimens unidentified as to polymer type.

Mechanical Properties

For measuring the linear densities and tensile properties of the single fibers from the felts, the procedure outlined in Phase I was generally followed. In these tests a rate of extension of 10% per minute was employed. Measurements were made on 20 to 25 specimens of each sample.

The results of these tests are presented in Table IX. The textile moduli and breaking tenacities of the nylon 66 and nylon 6 fibers from Style Nos. 2,3,9,5 and 8 are below the usual ranges for uncrimped filaments of the high-tenacity grade of these polymers[7]. Correspondingly, the breaking extensions are higher. These effects are the characteristic result of the crimping of fibers, by practically all methods. The setting of the crimp, as shown by the results on the nylon 66 fibers from Style 4 felt, evidently leads to a low modulus, further reduction in tenacity, and a further increase in extension at break.

The breaking tenacities and extensions (Table IX) for the polypropylene fibers fall within the rather wide, published[7] ranges for these properties, but the textile moduli are below the published range.

TABLE IX

MECHANICAL PROPERTIES OF SINGLE FIBERS

Style Number	Fiber Type	Linear Density (den)	Textile Modulus (g/den)	Breaking Tenacity (g/den)	Breaking Extension %
2	nylon 66	6.6	20.5	6.0	29.4
3	nylon 66	6.3	25.5	7.2	26.3
4	nylon 66*	6.9	18.7	4.6	31.8
9	nylon 66	6.5	17.2	6.6	27.8
5	nylon 6	6.9	24.2	5.5	21.4
7	polypropylene	6.0	12.0	4.7	32.0
8	polypropylene	6.5	10.2	4.6	36.9
	nylon 66	7.2	15.2	6.0	29.9

* Crimp-set fiber

A comparison of the present results with the mechanical properties recorded in Table IV leads to the inference that the stock used in the felts studied in Phase I may have been one of the newer nylon 66 materials of extra-high tenacity.

Length Analysis

The length analyses were made on fibers removed from the original felts, as well as on fibers extracted from the ruptured portions of specimens used in cohesion tests on the felt samples. Again, the WIRA method[5] was used. The number of fiber specimens involved in the test for each sample varied from 150 to 250. The results of the tests are recorded in Table X.

TABLE X

AVERAGE LENGTH OF FIBERS

Style Number	Fiber Type	From Felts Before Tensile Testing (in.)	From Ruptured Area of Felt Strips (in.)
2	nylon 66	3.18	2.76
3	nylon 66	3.38	2.87
4	nylon 66	2.71	3.29
9	nylon 66	3.80	3.26
5	nylon 6	2.62	3.00
7	polypropylene	3.42	3.07
8	polypropylene & nylon 66	3.00*	3.22*

* Average length including both components: polypropylene and nylon.

From these results, it appears that some fiber breakage occurs during tensile deformation of felt in the case of Style Nos. 2,3,9 and 7, as indicated by the reduction in average length. Surprisingly, the results for Style Nos. 4,5 and 8 exhibit an opposite trend. This behavior could be attributed to a multiplicity of causes, a few being the action of needling, fiber entanglement, steam pressing, thickness of the felts and efficiency of lamination of batts. The increase in the average fiber length on deformation could also be due to the removal of crimp in fibers in the rupture zone.

(2) Cohesion Properties of Felts

In accordance with the recommended standard procedure of ASTM for testing felts[6], five specimens of 2 inch x 8 inch dimensions were cut from the body of each of the seven needled felts listed in Table VII. The specimens were taken from the samples in a diagonal pattern (keeping the long axis of the specimens always parallel to the machine

direction of the felt), so as to be fully representative of the felt over its entire width. After conditioning, the specimens were weighed and then extended to rupture on a tensile tester at a gauge length of 4 inches, with a rate of extension of 50% per minute, duplicating the technique described in section 2a(2). The results of the cohesion tests are given in Table XI.

As pointed our previously, the comparison of forces, obtained in such cohesion tests as those made in this study, should take into consideration differences in one or another of the geometrical features of the felt samples that are compared. In the application of this principle, average maximum forces normalized to areal density were calculated (fourth column of Table XI).

A statistical analysis of results on the normalized maximum force and the observed extension to maximum force (Table XI) was made to assess the significance of differences in these two parameters between various felt samples. The comparisons were made with a view to ascertaining whether, so far as results in this quasi-static test are concerned, there are significant effects arising from
(a) the use of raw materials from different fiber producers,
(b) the use of crimp-set fibers and different polymer types,
(c) the blending of different fiber-forming polymers, and
(d) different amounts of needling (penetration density).
The results of this analysis, in terms of "Student" *t*-values, are given in Table XII.

Examination of the values in Tables XI and XII reveals that there is no significant difference between the normalized maximum forces of felts (Style Nos. 2 and 3) composed of nylon 66 fibers from the two different producers. Style No. 2, however, has a significantly higher extension to maximum force, by about 90%. The comparison of results on Styles 3 and 4 shows that the crimp setting of the nylon 66 fibers from producer "B" has no significant effect on the normalized force. This absence of an effect may reflect different interactions with the needle-punching process, between the regular-crimped and crimp-set fibers. Style No. 4, containing the crimp-set fibers, has a substantially higher areal density (by about 45%) than Style No. 3. Crimp-setting evidently has no effect on extension.

Comparisons of Style Nos. 2 and 3 with Style

No. 5 indicate that nylon 66 fibers yield felts of substantially higher maximum force (whether or not normalized) than do nylon 6 fibers. In only one of the nylon 66 felts (Style No. 2) is the extension to maximum force significantly different from that found for the nylon 6 felt. The data on Style Nos. 2,5 and 7 indicate that the difference in normalized force between the polypropylene (PP) and nylon 66 felts is not significant; the PP felt, however, has a substantially higher normalized force than the nylon 6, the difference being highly significant.

TABLE XI

COHESION PROPERTIES OF FELTS

(average values)

Style Number	Measured Areal Density (oz/sq yd)	Maximum Force (lb)	Normal. Max. Force $\left(\frac{lb/oz}{sq\ yd}\right)$	Extension to Max. Force (%)	Force at 25% Extension (lb)	Force at 50% Extension (lb)
2	19.0	118	6.2	50	5	12
3	13.5	88	6.5	26	3	7
4	19.7	138	7.0	24	7	19
9	17.0	125	7.4	18	7	27
5	15.5	56	3.6	25	3	8
7	12.7	72	5.6	13	5	13
8	21.0	166	7.9	20	13	40

TABLE XII

SIGNIFICANCE OF DIFFERENCES BETWEEN COHESION PROPERTIES OF FELTS

Style Numbers	Effect	Normalized Maximum Force	Extension to Maximum Force
2 vs 3	Fiber producer	0.66	3.08*
3 vs 4	Crimp setting	1.30	0.23
2 vs 5	Nylon 66 vs. nylon 6	6.45**	3.37**
3 vs 5	Nylon 66 vs. nylon 6	6.86**	0.16
2 vs 7	Nylon 66 vs. polypropylene	1.26	7.80**
5 vs 7	Nylon 6 vs polypropylene	7.69**	1.92
7 vs 8	Polypropylene vs. 50-50 blend	6.85**	1.33
2 vs 8	Nylon 66 vs. 50-50 blend	4.03**	4.52**
9 vs 2	Penetration density (ppsi)	2.14	5.09**

* Significant at 98% level
** Significant at 99% level

The highest maximum force, as well as normalized force, was registered by the felt (Style No. 8) composed of a blend of nylon 66 and PP fibers. The differences between its normalized force and those of the all-nylon 66 and all-PP felts are highly significant. It is difficult to assign a reason to the increase in cohesion arising from blending, since, presumably, this parameter is strongly dependent on the degree of inter-locking of fibers and on interfiber contact. Increasing the amount of needling so as to increase the penetration density from 277 to 454 ppsi, as was done in the production of Style No. 9 nylon 66 felt, brings about an apparent, but not statistically significant increase in normalized force, and a substantial decrease in extension to maximum force. These results are qualitatively in agreement with those in Table VI; however, in Table XI, the effects of increased needling are generally weaker with respect to maximum force, and stronger with respect to extension. Comparison of the two sets of data is confounded by the fact that needling seems, in Table VI, to lead to generally small increases in areal density of the felts, the opposite of the effect shown by the data in Table XI.

c. Discussion of Results

From the results of the studies made in this Phase, of fiber characteristics, on the one hand, and the cohesion properties of felts, on the other, it appears that processing variables, and interactions at the processing stage, are predominant factors in determining the cohesion of felts. The surface-roughness characteristics of the fibers in the samples used in this study were not sufficiently different from one another to permit any conclusion as to the influence of this parameter on the cohesion of the final product. No correlation can be seen between the mechanical properties of single fibers and the cohesion properties of the felts they compose. Thus, for example, while in the tensile tests on felts (Table XI) the nylon 6 (Style No. 5) showed a low normalized maximum force, in the fiber tests this sample had a textile modulus and breaking tenacity in the ranges of those of the nylon 66 samples (Table IX). Contrariwise, the PP sample (Style No. 7) which had a higher normalized force than the nylon 6, when tested in felt form, was composed of fibers having a distinctly lower textile modulus, as well as lower breaking tenacity. One can speculate that there are features of the fiber samples, other than those measured,

which may differ among these samples, such as the finishes used by the fiber producers; such differences may affect the behavior of the fibers in the felting process, and ultimately the performance of the felts produced.

It should be emphasized that it is not known what correlation exists between the parameters in the quasi-static cohesion tests employed in these studies, and the impact resistance of the felt samples, especially, the resistance to localized transverse loading under impact conditions, such as are encountered in the use of these materials in body armor. It is recommended that the evaluation of the seven felt samples (Style Nos. 2,3,4,9,5, 7 and 8) studied in this Phase be undertaken, by means of the standard "V_{50}" ballistic test. If a correlation can be found between the "V_{50}" limit and one or another of the parameters measured in the TRI cohesion test, the latter will provide a relatively simple and convenient method for the preliminary screening evaluation of experimental felts as candidate materials for personal body-armor applications.

4. References

1. The Felters Company, "A Needled-Felt Preparation Program," Progress Report No. 3, 6 May to 5 August, 1968; Contract No. DAAG17-68-0041, U. S. Army Natick Laboratories.

2. Scheier, S. C. and W. J. Lyons, Textile Res. J. 34, 410 (1964).

3. Scardino, F. L. and W. J. Lyons, Textile Res. J. 37, 874 (1967).

4. Scheier, S. C. and W. J. Lyons, Textile Res. J. 35, 385 (1965).

5. British Standards Institution, Methods of Test for Textiles, Handbook No. 11 (1963), p. 87.

6. American Society for Testing and Materials, ASTM Standards, Part 24, D461-67 (Oct. 1968), p. 107.

7. "Properties of the Man-Made Fibers," Textile Industries, September 1967.

DISTRIBUTION LIST

Copies	
1	Office of the Director of Defense R&E, Attn: Dr. Earl T. Hayes, Asst. Director Materials, The Pentagon, Washington, D. C. 20310
1	Director, Advanced Research Projects Agency, Department of Defense, Washington, D. C. 20310
1	Director, IDA/Weapons System Evaluation Group, Room 1E875, The Pentagon, Washington, D. C. 20310
1	Commanding General, U. S. Army Materiel Command, Attn: AMCRD-RC-M, Washington, D. C. 20315
1	Commanding General, U. S. Army Materiel Command, Attn: AMCRD-DM, Washington, D. C. 20315
1	Commanding General, U. S. Army Materiel Command, Attn: AMCRD-DM-A, Washington, D. C. 20315
1	Commanding General, U. S. Army Materiel Command, Attn: AMCRD-RP, Washington, D. C. 20315
1	Commanding General, U. S. Army Materiel Command, Attn: AMCRD-DF-S, Mr. E. Proudman, Washington, D. C. 20315
1	Commanding General, U. S. Army Aviation & Surface Materiel Command, Attn: TCMAC-EPP, 12th & Spruce Sts., St. Louis, Missouri 63166
1	Commanding General, U. S. Continental Army Command, Attn: Aviation Section, Fort Monroe, Virginia 23351
1	Commanding General, U. S. Army Combat Developments Command, Attn: CDCMR, Fort Belvoir Virginia 22060
1	Commanding General, U. S. Army Combat Developments Command, Attn: CDCRE, Fort Belvoir Virginia 22060
2	Commanding Officer, U. S. Army Mobility Equipment R&D Center, Attn: Technical Document Center, Bldg. 315, Vault, Fort Belvoir Virginia 22060
1	Commanding General, U. S. Army Combat Developments Command, Combined Arms Group. Fort Leavenworth, Kansas 66027

DISTRIBUTION LIST (CONTD.)

Copies	
1	Commanding General, U. S. Army Missile Command, Attn: AMSMI-R, J. McDaniel, Redstone Arsenal, Alabama 35809
1	Commanding General, U. S. Army Tank-Automotive Center, Attn: H. Spiro, Warren, Michigan 48090
1	Commanding General, U. S. Army Weapons Command, Attn: AMSWE-RDR, Rock Island, Illinois 61201
2	Commanding Officer, Army Research Office, Office Chief Research & Development, Attn: Physical Sciences Division, 3045 Columbia Pike, Arlington, Virginia 22210
1	Commanding Officer, Army Research Office (Durham), Box CM, Duke Station, Durham, North Carolina 27706
1	Commanding Officer, Development & Proof Services, Attn: STEAP-DS-TU, W. Pless, Aberdeen Proving Ground, Maryland 21005
1	Commanding Officer, Frankford Arsenal, Attn: SMUFA-1320, H. Markus, Philadelphia, Pennsylvania 19137
1	Commanding Officer, Limited War Laboratories, Attn: J. L. Baer, Aberdeen Proving Ground, Maryland 21005
1	Commanding Officer, Picatinny Arsenal, Attn: W. J. Powers, Dover, New Jersey 07801
1	Commanding Officer, U. S. Army Ballistic Research Laboratories, Attn: AMXBR, H. Kostiak, Aberdeen Proving Ground, Maryland 21005
1	Commanding Officer, U. S. Army Combat Developments Command, Combat Service Support Group, Fort Lee, Virginia 23801
1	Commanding Officer, U. S. Army Combat Developments Command, Air Defense Agency, Fort Bliss, Texas 79906
1	Commanding Officer, U. S. Army Combat Developments Command, Aviation Agency, Fort Rucker, Alabama 36362
1	Commanding Officer, U. S. Army Combat Developments Command, Transportation Agency, Fort Eustis, Virginia 23604
1	Commanding Officer, U. S. Army Materials and Mechanics Research Center, Attn: P. V. Riffin, Watertown, Mass. 02172

DISTRIBUTION LIST (CONTD.)

Copies	
1	Commanding Officer, U. S. Army Materials and Mechanics Research Center, Attn: G. A. Darcy, Jr., Watertown, Mass. 02172
1	Commanding Officer, U. S. Army Materials and Mechanics Research Center, Attn: AMXMR-AT, Watertown, Mass. 02172
1	Commanding Officer, U. S. Army Aviation Materiel Laboratories, Attn: F. P. McCourt, Fort Eustis, Virginia 23604
1	President, U. S. Army Aviation Board, Fort Rucker, Alabama 36362
1	President, U. S. Army Infantry Board, Fort Benning, Georgia 31905
1	Chief, Bureau of Naval Weapons, Attn: RMMO-5, Department of the Navy, Washington, D. C. 20390
1	Chief, Bureau of Naval Weapons, Attn: RAAV-5, Department of the Navy, Washington, D. C. 20390
1	Commander, Naval Air Development Center, Attn: WR-4, Johnsville, Pennsylvania 19112
1	Commander, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland 20910
1	Commander, U. S. Naval Ordnance Test Station, China Lake, California 93557
1	Commander, Naval Research Laboratory, Attn: Willard J. Ferguson, Anacostia Station, Washington, D. C. 20390
1	Commanding Officer, U. S. Naval Weapons Laboratory, Dahlgren,Virginia 22448
1	Commandant, U. S. Marine Corps, (AO3H), Washington, D. C. 20380
5	Headquarters, Aeronautical System Division, Attn: ASRCEE, Wright-Patterson Air Force Base, Ohio 45433
1	Detachment No. 4, ASD(ASQW), Eglin Air Force Fase, Florida 32542
1	SAWC (ICAG), Eglin Air Force Base, Florida 32542
1	National Aeronautics & Space Administration, Attn: R. V. Rhode, Washington, D. C. 20546
1	National Aeronautics & Space Administration, Attn: G. C. Deutach, Washington, D. C. 20546
1	National Aeronautics & Space Administration, Attn: B. G. Achhammer, Washington, D. C. 20546

DISTRIBUTION LIST (CONTD.)

Copies	
1	George C. Marshall Space Flight Center, Attn: Dr. W. R. Lucas, M-S&M-M, Huntsville, Alabama 35812
1	George C. Marshall Space Flight Center, Attn: W. A. Wilson, M-F&AE-M, Bldg. 4720, Huntsville, Alabama 35812
1	Commanding Officer, Air Force Materials Laboratory, (MAAE), Attn: R. E. Wittman, Wright-Patterson Air Force Base, Ohio 45433
1	Commanding Officer, U. S. Army Chemical Research & Development Laboratories, Attn: SMUEA-CR-ME, Mr. George M. Stewart, Edgewood Arsenal, Maryland 21010

INTERNAL DISTRIBUTION

23	Technical Plans Office (For Files and Transmittal to DDC)
2	Technical Library, NLABS
2	Military Liaison Representative, NLABS
5	Technical Editor, C&PLSEL
1	Officer-in-Charge, U. S. Navy Clothing and Textile Research Unit

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Textile Research Institute Princeton, New Jersey	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

A STUDY OF FELTS FOR PERSONAL ARMOR

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Preliminary Study, 1964-1969

5. AUTHOR(S) (First name, middle initial, last name)

W. James Lyons, Frank L. Scardino and B. C. Goswami

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1969	19	7

8a. CONTRACT OR GRANT NO. Contract No. DAAG17-68-C-0040 b. PROJECT NO. 1M624101D504 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) 70-13-CE; TS-164

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Natick Laboratories Natick, Massachusetts 01760

13. ABSTRACT

This study was concerned with the influence of various geometric and mechanical characteristics of the constituent fibers, and some processing factors such as the amount of needling and the blending of fibers, on the cohesion of needled felts. Tests conducted on single fibers for surface-roughness and frictional force characteristics (the latter only in Phase I of the program), and mechanical properties. Length analyses were also made on groups of fiber samples.

The observed surface-roughness parameters did not differ sufficiently among the various samples to permit any conclusions regarding the influence of this property on the cohesion of felts. The frictional-force measurements failed to provide any data that could be significantly correlated with the cohesion behavior of felts.

From the length analyses of the fibers taken from the felts before and after deformation, there was apparently no fiber breakage during the rupture of felts. This observation, and the results obtained on the mechanical properties of single fibers and cohesion of felts, led to the conclusion that fiber tenacity does not play an important role in determining the cohesion of needled felts.

The felts made from fibers having no crimp had greater cohesion. Increased needling brought about a slight, though not significant, increase in cohesion.
(Cond'd)

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

UNCLASSIFIED
Security Classification

In general, the results of the study showed that processing variables such as amount of needling, the blending of fibers differing in single-fiber properties (blending of polypropylene and nylon 6,6 in the present study), and interactions at the processing stage seem to be the predominant factors influencing the cohesion properties of felts.

In an extension of this study, ballistic tests will be made on the seven felt samples studied in Phase II to determine whether a correlation can be drawn between the results of such ballistic tests and the cohesion properties of felts.